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(54) Title: CONTROL OF MULTIPLE FUEL CELL POWER PLANTS AT A SITE TO PROVIDE A DISTRIBUTED RESOURCE IN A UTILITY GRID

(57) Abstract: A site management system (11) is provided for a power system (8) at site in a utility distribution grid (10). The power system (8) includes multiple fuel cell power plants (18) and one or more loads (14), for selective connection/disconnection with the grid (10). The site management system (11) operates to control the power plants (18) in an integrated manner, alternatively in a grid connected mode and in a grid independent mode. The utility is able to view and treat the multiple power plants (18) at the site as a single, unified distributed resource on the grid (10). The site management system (11) provides signals representative of the present power capability (kw Capacity-88) of each of the power plants (18), and a signal (Total Kw Capacity -95) representative of the total present power capability at the site. These power representations are used to appropriately assign power dispatch loadings to the respective fuel cells (18) I the grid connected mode and in the grid independent mode. The site management system (11) also functions in the grid independent mode to monitor present demand of the loads (14) and, if necessary, to shed loads (14) in accordance with a predetermined schedule.

CONTROL OF MULTIPLE FUEL CELL POWER PLANTS AT A SITE TO PROVIDE A DISTRIBUTED RESOURCE IN A UTILITY GRID

Technical Field

This invention relates to the control of fuel cell
5 power plants, and more particularly to the control of
multiple fuel cell power plants at a site. More
particularly still, the invention relates to the control
of multiple fuel cells at a site to provide a distributed
resource in a utility grid.

Background Art

10   Individual fuel cells have been used both
experimentally and commercially in various configurations
to power various electrical loads. In the main, the
applications have relied on a single fuel cell, or fuel
15 cell power plant, to supply electrical power to one or
more loads at the site. While such sites may be mobile,
as in the powering of the electric drive motor of a
vehicle, in the main they are large and stationary. These
applications have typically been individual commercial
20 installations or buildings, perhaps involving computers
or similar electronic data processing equipment or
medical equipment requiring a reliable source of power.
    To operate such fuel cell power plants, there are
normally associated various controls for the direct
25 control of the fuel cell itself and its production of DC
electrical power, as well as additional controls for
converting the DC power to AC power, for connecting and
disconnecting power with the loads, etc. In some
instances, the fuel cell power plant is connected to the
30 loads in parallel with the normal electric utility grid,
and may act in lieu of, or in addition to, the grid to
supply power to the loads. In other instances, there may
be multiple fuel cell power plants at a site,
collectively connected to the loads in parallel with the
35 utility grid. However, even in such configuration, the

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control of the fuel cells has typically been on an
individual basis, with little or no provision for an
integrated control arrangement to optimize the use of
multiple fuel cell power plants interconnected with the
5 utility grid and the loads.

       When one or more fuel cell power plants are
connected to the utility grid as well as the loads, they
are said to be in a grid connected (G/C) configuration or
mode. Alternatively, when those fuel cell power plants
10 are connected only to the loads, they are said to be in
grid independent (G/I) mode. In the G/I mode, the fuel
cell power plants typically follow the load and apportion
the load among the power plants. The transition from one
such mode to the other, and the control of multiple fuel
15 cell power plants relative to the loads present
additional control complexities that have impeded the
efficient and economic utilization of multiple fuel cell
power plants as distributed resources in electric utility
grids.
20   Accordingly, there is a need for a control
arrangement for the efficient and economic utilization of
multiple fuel cell power plants at a site as a
distributed resource in a utility grid.

Disclosure of Invention

25   The present invention concerns the control of
multiple fuel cell power plants at a site, particularly
as a distributed resource for inclusion in a utility
grid. The invention further concerns the unified, or
integrated, control of multiple fuel cell power plants at
30 a site, both in a grid connected (G/C) mode to facilitate
their use as a distributed resource in a utility grid
network and in a grid independent (G/I) mode to optimize
their value and utility as an/the independent power
supply to one, or typically multiple, customer loads at
35 the site.

Accordingly the present invention relates to a fuel
cell-powered generating system at a site for inclusion as
a distributed generating resource in a distributed
generation utility power grid, and comprises multiple
5   fuel cell power plants at the site, at least one, and
typically multiple, loads located substantially at the
site, and a site management system operatively connected
to the multiple fuel cell power plants, the one or more
loads, and the utility grid for controlling the fuel cell
10 power plants in an integrated, or unified manner, in,
alternatively, a grid connected mode of operation having
the fuel cell power plants connected to the load(s) and
to the power grid, and a grid independent mode having the
fuel cell power plants connected to the load(s)
15 independent of connection to the power grid. This
integrated control provided by the site management system
allows the utility to view the multiple fuel cell power
plants at the site as a single, or unified, distributed
generating resource when connected to the grid.
20 Accordingly, as used in this context, the terms
"integrated" and "unified" are viewed as being
substantially synonymous. Moreover, the integrated
control facilitates the operation of the site in the G/I
mode where the fuel cells are typically load-following
25 and have operated independently of one another. In this
latter regard, the integrated control in the G/I mode
further facilitates a load management (sharing and
shedding) capability for assuring power to critical
loads.
30   The fuel cell power plants each include control and
logic capabilities for folding back (reducing) rated
power levels to lesser levels, if necessary, in response
to various power plant conditions, and for providing
signals representative of the instant power level
35 capability of the respective plants. As used herein in
association with power capacity and load demand, the term
"instant" is intended to be synonymous with "present",

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"current", or "instantaneous". The site management system
sums the individual power capacities of the respective
fuel cell power plants and obtains a measure of the total
instant power capacity of the multiple power plants at

5   the site. This measure of total power capacity and the
respective individual power capacity measures are used to
provide a site power measure to the utility grid and to
appropriately load each of the power plants in G/C mode,
and are used in the G/I mode to appropriately load each

10   of the power plants to operate in a unified manner and
further, for a load shedding function. In this latter
regard and assuming multiple loads, the site management
system is operative to recognize the instant load demand,
the instant total power capacity, and a predetermined

15   prioritization of the loads in the event load demand
exceeds instant total power capacity, and to selectively
shed or disconnect loads in accordance with the schedule,
if necessary.

The site management system includes at least one,

20   and typically several, signal processing logic
controllers cooperatively interacting with one another,
the multiple fuel cell power plants, and the utility grid
to perform the integrated control functions of the
invention.

25   The foregoing features and advantages of the present
invention will become more apparent in light of the
following detailed description of exemplary embodiments
thereof as illustrated in the accompanying drawings.

Brief Description of Drawings

30   Fig. 1 is a simplified schematic block diagram of a
power system, employing multiple fuel cell power plants
at a site, as a distributed resource in a utility grid
system and a backup power source to one or more loads
located at the site when the grid is unavailable;

35   Fig. 2 is a generalized, functional schematic block
diagram illustrating the development of a signal

representative of the present power generating capacity
of a respective fuel cell power plant; and

Fig. 3 is a generalized, functional schematic block
diagram algorithmically illustrating the power dispatch
5 loading of multiple fuel cell power plants when operating
in the G/C mode.

Best Mode for Carrying out the Invention

Referring to Fig. 1, there is depicted a simplified
block diagram of a fuel cell-based power system 8 in
10 accordance with the invention, which is readily available
and utilized at a site as a distributed resource in a
utility grid system. The power system 8 is connected to
utility grid bus 10, and employs multiple fuel cell power
plants 18 located at a common site, for supplying, with
15 the grid 10, 3-phase power to, and through, load
contactor array 13 to loads 14, usually also at the same
site. In the preferred and normal instance, the fuel cell
power plants 18 provide power to the loads 14 on a
substantially continuous basis, irrespective of
20 occasional disconnects of the utility grid 10 from the
power plants 18 and loads 14. Switching gear, generally
designated 12 and described below, includes a static
switch that rapidly opens during utility grid
disturbances to isolate the loads 14 and the fuel cell
25 power plants 18 from the grid 10, and the fuel cells
provide substantially continuous power to the loads
during these disturbances. For simplicity, a "single
line" diagram, or representation is used herein to depict
the 3-phase supply lines, as well as their included
30 switches and other circuit components. Similarly, with
respect to the control circuitry forming part of this
invention, it will be understood that single-line
representations have often been used for twisted pairs,
or grouped parallel leads, which serve as signal
35 conductors. For convenience of explanation and visual

distinction, the portions of the schematic carrying the
relatively higher voltage/current/power to the loads **14**
are bolded, in contrast with the lower-voltage, control
portions of the system **8**.

5   The grid **10**, the fuel cell power plants **18**, and the
loads **14** are interconnected and controlled through a Site
Management System (SMS), represented by broken line block
11. The loads **14**, here designated L_1, L_2, . . .L_x, are
those of the customer at the site, and typically include

10 one or more "critical" loads, such as computers,
electronic data processing devices, and/or medical
devices, that require a substantially continuous supply
of power. Others of those loads **14** may be less critical,
being able to tolerate brief or longer-term power

15 interruptions. In a typical contactor array **13**, there may
be 12 individual, separately-controllable, contactors
i.e., 1, 2, . . X, with respective loads L_1, L_2 . .L_x
connected to a terminal thereof. Selective actuation of
the individual contactors may be used to selectively

20 connect and disconnect the respective loads from the
power sources, as will be described hereinafter.

        The utility grid bus **10**, following step-down by
transformer **20**, normally provides power at 480 Vac and 60
Hz, as also do the fuel cell power plants **18** via lead, or

25 bus, **15**, through the delta-to-wye transformer **27**.
Switching gear, **12** serves to interconnect the fuel cell
power plants **18** through bus **15**, the loads **14** through a
load power bus **39**, and the utility grid **10**. In this way,
the fuel cell power plants **18** (or simply "fuel cells **18**"

30 or "power plants **18**") are available and connected for
supplying power on a full time basis to the loads **14** or
to the loads **14** and utility grid **10**, for economical usage
of the fuel cells. The switching gear **12** preferably
includes a high current capacity, high speed, static

35 (solid-state) switching arrangement and several inter-tie
or breaker switches (not shown). The static switch,

which may be pairs of counter-connected, silicon
controlled rectifiers, serves as the main operational
switch, and is closed during normal operation of the grid
10, to connect the grid 10 with the power plants 18 and
5 loads 14, and is open if the grid goes out of limits or
if an "enable" signal is removed. The switching
arrangement can be of a type well known in the art, such
as a 3 pole electrically operated static switch, rated at
2000 amperes and capable of performing seamless switching
10 transfers of power in about ¼ cycle (about 4 ms). The
breaker switches are typically electromechanical and may
be automatically or manually actuated to selectively
provide bypass paths around the static switch and/or to
open otherwise closed paths. Global bypass breakers 19
15 connected to busses 15, 10 and 39, serve, when manually
closed, to further bypass the switching gear 12, as
during maintenance or a start-up or shutting down
operation.

       There are multiple fuel cell power plants 18 at the
20 site, and it is the integrated control of and/or
involving, those multiple power plants 18 which comprises
the present invention. In an exemplary arrangement, five
(5) such power plants 18 are located at the site and
controlled by the SMS 11. Each power plant 18 is a 200 kw
25 International Fuel Cells, LLC (formerly ONSI) PC25™C
power plant, with the five units collectively being
capable of providing up to 1 megawatt of power. Each such
power plant 18 includes the basic fuel cell (F.C.), a
Power Plant Controller (PPC), and a Power Conditioning
30 System (PCS) which includes its own separate controller.
The fuel cell, F.C., includes (not shown) a fuel stack
assembly, ancillary fuel processing and delivery
equipment, oxidant delivery equipment, and a water and
steam management system, as is generally well known. The
35 PPC includes the controls, logic and monitoring equipment
directly associated with the operation and control of the

respective F.C., as generally known, and including
additional provision for evaluating the present power
generating capability of the power plant 18, as will be
described. The PCS contains a solid-state inverter and

5   its controller which converts DC power to AC power at the
desired voltage and frequency. Control of and by the PCS,
as through its associated controller and the other
controllers to be hereinafter discussed, further enables
conversion of the mode of operation of a power plant 18

10 from G/C to G/I, and vice versa, as is generally known.
When used in G/C mode, the variable controlled by the PCS
is power delivered (both real and reactive). When used in
the G/I mode, the variables controlled are output voltage
and frequency, and, if multiple power plants 18 are

15 involved, phase. The output voltage of a three-phase
system is, of course, controlled to be at a phase angle
of 120^0 between each phase. The outputs of the several
fuel cell power plants 18 are collectively joined by bus
15. Control signals may be exchanged between the several

20 component portions of a power plant 18, i. e., the F.C.,
PPC, and PCS, via one or more signal paths, here
collectively depicted for convenience as a common signal
bus and I/O port 30.

In addition to the switching gear 12, the SMS 11 for

25 the site includes three controllers which are responsible
for coordinating integrated operation of the multiple
power plants 18, first with respect to each other and
with respect to the customer loads 14, and ultimately as
a single power resource with respect to the utility grid.

30   A Site Management Controller (SMC) 31 provides
direct control of the PCSs of the fuel cells 18 in
response to mode indicating/controlling signals M1 and M2
on lead 40 from logic associated with the static switch
of switching gear 12, and further in response to a grid

35 voltage reference signal 10' provided by grid sensing
circuitry 37. The grid sensing circuitry 37 typically

includes a potential transformer (sensor) and a current
transformer (sensor) to sense the voltage and current of
grid 10 and provide respective signals thereof. The mode
signals M1 and M2 from switching gear 12 are indicative
5 of switching of the static switch, and thus the need for
a mode change from G/C to G/I, or vice versa. Logic
associated with the static switch receives a signal via
lead 10'' from the grid sensing circuitry 37 and
determines whether the grid is within limits or not. A
10 change in this condition acts through the logic to
"toggle" the static switch, and to signal such action via
the M1 and M2 signals on lead 40. When the grid is out of
limits, the M2 mode signal transitions from an "Off" to
an "On" state to signal a need for, and to initiate, a
15 mode change. Similarly, but slightly delayed, when the
static switch has actually opened in response to the
sensed out of limits condition of the grid, the M1 mode
signal transitions from an "Off" to an "On" state to
signal nominal completion of the mode change. The reverse
20 occurs when the sensing circuitry determines that the
grid power supply has been returned to within acceptable
limits, with the M2 signal again leading the M1 signal.
The SMC 31 also includes provision for issuing load share
control signals to each of the PCSs of the respective
25 fuel cells 18, to apportion the load among the fuel cells
18 during load following operation in the G/I mode. That
load sharing typically takes into account the present
power generating capacity of each fuel cell 18, as
provided by status signals from the fuel cell power
30 plants 18, and apportions the load accordingly amongst
them.

The SMC 31 is typically composed of computers,
programmable logic, sensors, and control circuitry. The
combination of the mode signals M1 and M2, and the
35 information about grid voltage, phase and frequency
provided on lead 10', serve in the SMC 31 to provide, as

outputs, further mode control signals D1 and D2 on lead 33', a phase lock loop sync signal on lead 33'', and a voltage reference signal on lead 33'''. A signal bus 33 exchanges these control signals between the SMC 31 and

5   the PCSs of the several power plants 18. The signal bus 33 also conveys, between the SMC 31 and each of the PCSs, the several load share status and control signals collectively represented as lead 33'''' to/from the SMC 31. These signals are used to apportion the load among

10 the fuel cells 18 during load-following operation in the G/I mode. The "load sharing" algorithm takes into account the present power generating capacity of each fuel cell 18, as provided by status signals from the fuel cell power plants 18, and apportions the load accordingly

15 amongst them.

       The grid 10 voltage and current signals sensed by the grid sensing circuit 37 are also extended to a grid protection relay 26, which in turn is responsive to the grid voltage and current being in or out of limits to

20 provide a control signal on lead 28. The lead 28 is connected to the switching gear 12, and the signal thereon serves to control one or more breaker switches in a manner to assure the load continues to have power during grid disturbances and also to protect the static

25 switch, the grid 10, the power plants 18 and/or the loads 14 in the event of extreme conditions.

       A second controller is the Load Shed Controller (LSC) 34, which is a programmable logic control comprised of appropriate standard integrated circuits. The LSC 34

30 provides high-speed load shed control in the G/I mode, as will be described below. The LSC 34 receives respective kilowatt (Kw) capacity signals from each of the power plants 18 (1 through n) via a signal bus 36, here collectively representative of all "n" of the signals.

35 The respective Kw capacity signals are typically developed in the respective PPCs of each power plant 18,

pass through the respective PCSs, and each extend to the LSC 34 via I.O. port 30 as a 4-20 ma signal via respective pairs, here collectively represented as lead 36. The development of the Kw capacity signals at the

5 PPCs, and their eventual use in the various controls of the SMS 11, will be described below in greater detail. Suffice it to say at this juncture that the Kw capacity signals are a measure of the power generating capacity of the individual power plants 18, and find use in load

10 sharing, load shedding, and in the overall control of the multiple power plants 18 as a unified, or singular, resource in a utility grid of distributed resources. Further, 2X signals (possibly 24 in number) are communicated between the LSC 34 and the X (possibly 12 in

15 number) contactors 1 through X of the contactor array 13 via discrete signal lines, here represented for simplicity as a single lead 70. Half of these signals are representative of the status of the respective contactors, and the other half are responsible for

20 controlling the opening or closing of the respective contactors. The LSC 34 also receives an indication, via lead 71 from the logic associated with the static switch of switching gear 12, of the mode status, and particularly entry into the G/I mode. This enables

25 operativeness of the load shedding function in that mode, and vice versa.

The third controller is the Site Supervisory Controller (SSC) 29, which provides the operator interface for the power system 8, is responsible for

30 integrated supervisory control of the system at a high level, and provides an interface between the customer (or operator) at the site and the utility. As with the LSC 34, the SSC 29 is a programmable logic control comprised of appropriate standard integrated circuits programmed to

35 perform the required functions. A bus extender 38 connects the LSC 34 and the SSC 29 such that the two may

be viewed collectively as a unit. The SSC 29 includes six
interfaces with the remainder of the power system 8, as
well as with the utility grid.

      One of those interfaces is the interconnection of
5   the LSC 34 with the SSC 29 via the bus extender 38. The
LSC 34 communicates the 2X number of signals associated
with contactor array 13 to the SSC 29 approximately every
half second such that the SSC 29 has override capability
of the customer load contactors 13 as well as monitoring
10 the customer load status, when in G/I mode.

      Another interface involves the communications
between the SSC 29 and the individual power plants 18 via
n pairs of Local Operator Interface (LOI) leads 54', only
one being shown connected to the SSC 29, and the
15 connection with the PPCs of the power plants 18 being
represented, for simplicity, as but part of a cumulative,
multiple path, diverse signal communication bus 54. These
signals include those necessary for the routine
supervisory control of the power plants 18, and are used
20 to obtain data from the power plants 18 for both local
display on the Local Human Machine Interface (HMI) 56 and
for use at the utility dispatch Supervisory Control and
Data Acquisition (SCADA) interface on lead 58 from/to the
utility. A panel control 60 includes manual controls for
25 various annunciators and, particularly, a mode switch
input providing selection between a local operating mode
(L) in which the power plants 18 are controlled
individually, and a supervisory mode (S) in which the
several power plants are operated as a unit. When the
30 mode selector switch from panel control 60 is in the
supervisory mode (S), as depicted in Fig. 1, both the
Local HMI 56 and a Remote HMI 62 are inhibited from
issuing control or dispatch commands. Then, all control
and dispatch signals come from the utility's remote
35 dispatch station (not shown) via the SCADA interface line
58, which is a Modbus remote terminal link comprised of a

leased (dedicated) copper pair. The Remote HMI **62** is
connected with a remote site, such as the power plant **18**
manufacturer and/or the utility, by phone line through a
local modem **64**, and conducts data and control commands

5   from and to the Power Plants **18** via leads **54** and **54''''**
only when the mode selector switch is in the local mode.
The Local HMI **56** conducts data and control commands from
and to the power plants **18** via leads **54** and **54'**, with the
interaction of the SSC **29**, only when the mode selector

10   switch is in the local mode (**L**). The connection between
the local HMI **56** and the SSC **29** represents a third
interface with the SSC **29**. Similarly, the Remote HMI **62**
is connected with a remote site, such as the power plant
18 manufacturer and/or the utility, as by a phone line

15   through a local modem **64**, and conducts data and control
commands to and from the power plants **18** via the Local
HMI **56**, the SSC **29**, and the leads **54** and **54'** only when
the mode selector switch is in the local mode (**L**).

A fourth interface with SSC **29** involves the grid
20   protection relay **26** via lead **65**. This connection reports
the status of grid **10**, and any faults or out of limit
conditions therewith, such as current, voltage, phase or
frequency abnormalities, as discerned by grid sensing
unit **37** and applied through the GPR **26**.

25   A fifth interface with the SSC **29** involves the
provision of signals indicative of the power delivery by
the several power plants **18**, by means of a utility power
meter **66** connected to power bus **15** and having a signal
lead **67** connected to SSC **29**, and indicative of the power
30   delivered to/drawn by the loads **14**, by means of a utility
power meter **68** connected to load power bus **39**. The power
meter **68** is connected to bus **39** intermediate the
contactors **13** and the global bypass **19**, and has a signal
lead **69** connected to SSC **29**. The power meters **66** and **68**
35   each typically include a potential (voltage) sensor and a

current sensor (neither shown) for cumulatively
determining power. These power readings are used by the
SSC **29** and the LSC **34** for control actions to be
hereinafter explained.

5   The sixth interface involves 2-way communication
between the SSC **29** and the switching gear **12**, as
represented by the lead **72**. The SSC **29** may provide
discrete signals to the static switch control and to
selected breaker switches to allow it to select the

10   operating mode of the SMS **11** if necessary. Similarly,
those switches return respective status signals to the
SSC **29**. The SSC **29** may provide an "enable" signal to the
static switch, and when present allows the switch to
operate autonomously based on the condition of grid **10** at

15   the time. When the signal is "disabled", it forces the
static switch to open and cause power system **8** to operate
in the G/I mode.

       A local diagnostic terminal **73** is connected
selectively through an "n-way" switch **74** and leads **54''**

20   and **54**, to the individual ones of the n-number of power
plants **18** for obtaining diagnostic data. Also included is
a remote diagnostic terminal (RDT) **61** connected through
an "n-way" phone line sharer **63** to the individual n-
number of power plants **18**, via leads **54** and **54'''**, for

25   similarly obtaining diagnostic data.

       Reference is now made to Fig. **2**, which depicts a
generalized functional schematic block diagram of the
development, in the **PPC** of a respective power plant **18**,
of a Kw capacity signal (**Kw Capacity**) indicative of the

30   present power generating capacity of the respective fuel
cell power plant **18**. This signal is then used, both on an
individual plant basis and on a cumulative power system **8**
basis, to enable and facilitate remote dispatch of power
requirements by the utility in the G/C mode, as well as

35   load sharing and load shedding capabilities in the G/I
mode. A Kw rating value (**KwRATING**) is initially assigned

to a respective fuel cell power plant 18, as represented
on input lead 76 to an Event Table 77. The KwRATING
signal has a normal default value of 200 Kw, which
assumes the fuel cell and plant are operating, or

5   operable, at full capacity. This value may be adjusted by
an operator or the manufacturer to reflect a lesser value
in view of predetermined circumstances which may degrade
performance of the plant by a prescribed amount. The
Event Table 77 contains several power foldback values,

10 each of which correspond with one or more "abnormal"
conditions in the operation of the fuel cell F.C. portion
of the power plant 18. For instance, for conditions of
low steam to fuel ratio in the fuel cell system, the
power rating may be folded back to 170 Kw, and for

15 conditions such as inability to satisfy fuel demand,
insufficient make-up water, excessive fuel cell cabinet
temperature, etc., the foldback may be greater, to a Kw
rating of only 75 Kw. These foldback power values (and
others) are depicted on the scale appearing at the top of

20 table 77, whereas in fact the table serves to correlate a
sensed condition with a predetermined foldback power
rating and provide as an output, a signal on lead 78
which is representative of a folded back power rating.
This signal is applied to a lesser select function 79,

25 which has as its other input the initial KwRATING value
from lead 76. The lesser power value of the signals on
leads 76 and 78 is then provided as the output on lead
80. A further possible power foldback may be made at the
summer 81, which receives a (+) input from lead 80 and

30 may receive a (-) input on lead 82. The lead 82 contains
any power foldback magnitude resulting from a sensed
abnormality in the water treatment system for the fuel
cell, and that foldback magnitude is variable and may
range from a power decrease of as little as 0 Kw to as

35 much as 190 Kw. In this instance, the value appearing on
lead 80 will be reduced by the value appearing on the

lead **82**, to provide a resultant output on lead **83**. The value on lead **83** may also, or further, be folded back, or overridden if the fuel cell water treatment system is placed in a maintenance mode. This potential override

5　results when a water treatment maintenance mode signal **84** is applied to a Table **85**, which Table is scheduled to provide, as an output on lead **86**, either the value on lead **83** if the water treatment is operating normally or a preset folded back value of only 10 Kw if the mode signal

10　on **84** indicates the maintenance mode. The value on lead **86** is compared with that on lead **83** at the lesser select function **87**, and the lesser value is then provided as the **Kw Capacity** signal on lead **88**. Thus it will be realized that under normal operating circumstances and conditions,

15　the **Kw Capacity** signal may be as large as 200 Kw; whereas if one or more of the other conditions arise or exist, the rating will be folded back to a value between 200 kw and 10 kw, accordingly. This, then, represents the power generating capacity of that power plant **18** at that

20　moment. The various contributing parameters are monitored at least as frequently as 0.5 sec. such that the **Kw Capacity** signal may be updated and sent every 0.5 seconds.

　　　　Referring further to Fig. **2**, a **Set Power** value

25　(designated **112** in Fig. **3** below) is applied to lead **90**, and is the result, for a single power plant, of the total power dispatch signal (designated **97** in Fig. **3** below). The total dispatch is apportioned among the multiple power plants in accordance with the algorithm to be

30　described with respect to Fig. **3**, and the resulting **Set Power** is indicative of a desired or commanded level of power output from the respective single ones of the power plants **18**. This total dispatch value may be set by the utility via the SCADA input **58** to SSC **29**, and is

35　conditioned by the algorithm depicted in Fig. **3** to provide the resultant **Set Power** value. This **Set Power**

value on lead 90 is compared with the Kw Capacity value

on lead 88 at lesser select function 91, and the lesser

of the two is then available as the control signal DISPKW

to command the level of power to be dispatched by that

5 power plant 18. The output of lesser select 91 may be

extended through G/C ramp logic 92, such that the DISPKW

signal on lead 93 will change levels at a predetermined

rate so as to insure relatively smooth power transitions,

particularly when transitioning between G/C and G/I

10 modes. Each Kw Capacity signal is passed through the PCS

of a power plant and, from a current transducer in the

PCS, is passed to LSC 34 via lead 36. Each DISPKW signal

on a lead 93 represents a command signal sent from a

respective PPC to a respective PCS for regulating the Kw

15 power output of the respective power plant 18.

Referring to Fig. 3, there is a generalized

functional schematic block diagram of logic, typically in

the SSC 29, that determines the power dispatch loading of

the multiple (1 through n) power plants 18 when operating

20 in the G/C mode. The Kw Capacity signals for/from each of

the n fuel cell power plants 18 are cumulatively applied

as inputs to a summer 94 to provide a Total Kw Capacity

signal as the output on lead 95. This signal represents

the total power generating capacity of the power system 8

25 at that moment. The Total Kw capacity signal is provided

as one input to a lesser select function 96, with another

input being a UTILITY DISPATCH signal on lead 97. The

UTILITY DISPATCH signal may be derived from a demand

signal received from the utility via SCADA line 58. The

30 output of the lesser select 96 appears on line 98, and is

thus the ACTUAL DISPATCH value. In other words, the

actual dispatch value is the lesser of those two input

values, and can never be more than the Total Kw Capacity.

The ACTUAL DISPATCH value is then ratioed with, or

35 divided by, the Total Kw Capacity value in the division

function block 99 to provide an output value represented on lead 100. In the event the UTILITY DISPATCH value is equal to or greater than the Total Kw Capacity value, the output 100 will be unity (one), whereas if the UTILITY

5   DISPATCH request is less, then the output 100 will have some fractional value less than one. This value on line 100 may be deemed a weighting, or pro rating, factor. It is applied as an input to each of n multiplier function blocks 110, which function blocks have the Kw Capacity

10   value for that respective power plant as their other input. The products of these multiplication functions are the respective SET POWER signal values appearing as outputs on lines 112, and used as the SET POWER value on line 90 in Fig. 2. In this way, the SET POWER demand

15   signal for each power plant 18 (1 through n), is the ratioed amount of that plant's Kw capacity, and can never be greater than its capacity. In the instances when the UTILITY DISPATCH value is equal to or greater than the Total Kw Capacity, each plant will be loaded to its

20   present maximum capacity. Conversely, if the ratio is less than unity, each plant will be loaded to that ratioed amount of its present capacity.

An alternative to the algorithm depicted with respect to Fig. 3 is one which initially assumes that all

25   power plants have equal capacity and thus, divides the UTILITY DISPATCH request value by the number of fuel cell power plants (n) to obtain an initial "per power plant" dispatch value. The relevant logic then compares the Kw Capacity signal for the first power plant 18 (#1) with

30   the initial "per power plant" dispatch value and, if sufficient capacity exists, the requested value is put in that power plant's power dispatch register. The same is done for the remaining fuel cell power plants (#2 through n). If a particular fuel cell power plant 18 is limited

35   and can not supply the full requested "per power plant" dispatch value, then it is loaded to its power-limited

capacity and the remainder is stored in an overflow
register or the like. When all fuel cells **18** have been
polled and loaded based on their respective kilowatt
generating capacities, then the Kw amount accumulated and
5   stored in the overflow register is distributed amongst
the fuel cells **18** with remaining, or extra, power
generating capacity, using the same logic as described
above. This process continues iteratively until either
the entire dispatch request has been assigned to the
10 power plants **18** or no additional capacity remains for the
overflow dispatch request. If the latter occurs, an alarm
message is sent to the utility's dispatch center via line
58, stating that the power request exceeds the current
generating capacity of the site.

15   During operation of the site-based power system **8** in
the G/C mode, not only is the total capacity of the n
fuel cell power plants **18** available to supply the demands
of the local customer loads **14**, but the nominally
"infinite" resource of the utility grid **10** is also
20 available. However, when operating in the G/I mode, the
maximum power available is that represented by the **Total
Kw Capacity** value **95** depicted in Fig. 3. In such
instance, if the actual total power demand of the
collective loads **14** (L_1, L_2, ... L_x) is greater than the
25 **Total Kw Capacity** value, as because the latter is reduced
because of power "foldbacks" at the power plants **18**, some
administrative action must be taken. According to an
aspect of the invention, the customer loads **14** are
arranged, or identified, according to a schedule of
30 priorities. In the most refined instance, each of the
total X number of loads has its own different relative
priority. Alternatively, the loads **14** may be grouped, as
for instance in high, medium, and low priority groups.

Then, in one embodiment, the total power demand of
35 the loads **14**, as indicated by the signal **69** from Utility
Power Meter **68**, is conveyed to SSC **29** where it is

compared with the Total Kw Capacity signal 95 (of Fig. 3)
to determine whether or not there is sufficient capacity
to meet the instant demand of the loads. If there is,
then that demand is met according to the established

5 system load-sharing algorithm in SMC 31. However, if that
comparison, by subtraction or ratio or other convenient
means, indicates that the instant load demand is greater
than the Total Kw Capacity, a load shedding condition
arises. This is done in accordance with the previously

10 determined schedule of priorities, by disconnecting
(shedding) certain ones, or groups, of the loads 14
(L_1, L_2, ..L_x) by selective actuation (opening) of the
respective individual load contactors 13 (1, 2, .. X) by
the control signals represented by lead 70 between the

15 LSC 34 and the contactors 13. The LSC 34, in conjunction
with SSC 29, will then use the load priority schedule to
actuate (open) those contactors 13 required to disconnect
the lower priority loads and retain connected the more
critical, higher priority loads. In one configuration,

20 the loads can be shed sequentially by priority through an
iterative process until the demand can be met by the
Total Kw Capacity. In another, more sophisticated,
arrangement, the instant demand of the load associated
with each separate contactor 13 (1, 2, .. X) might be

25 determined by associating power meters with each
contactor and using the information to compute, according
to the priority schedule, which loads to disconnect in a
single disconnection action. Of course, with either
configuration, because the usage pattern of the loads 14

30 may be constantly changing as loads are "turned on and
off" by the user, it is necessary to continually repeat
this analysis and control action in the G/I mode to avoid
overloading. When a power foldback condition is removed
and/or certain higher priority loads are removed or

35 "turned off", some or all of the lower priority loads
previously shed may be reconnected to the load power line

39. In this way, the most critical customer loads always have power.

The logic functions depicted in Figs. 2 and 3, as well as the many other logic functions performed by the
5 invention, may be done with dedicated logic or via programmable logic circuitry, with the latter in the extreme instance being performed via one or more appropriately programmed computers.

Claims

1. 1.   A fuel cell-powered generating system (8) at a site
2. for inclusion as a distributed generating resource in a
3. distributed generation utility power grid (10),.
4. comprising:
5.   a. multiple fuel cell power plants (18_{1-n}) at
6. the site;
7.   b. at least one electrical load (14) located
8. substantially at the site; and
9.   c. a site management system (11) operatively
10. connected to each of the multiple fuel cell power
11. plants (18_{1-n}), the at least one load (14), and the
12. utility grid (10) for controlling the multiple fuel
13. cell power plants (18_{1-n}) in an integrated manner, in,
14. alternatively:
15.   i. a grid connected mode of operation
16. having the fuel cell power plants (18) connected to the
17. at least one load (14) and to the power grid (10), and
18.   ii. a grid independent mode of operation
19. having the fuel cell power plants (18) connected to the
20. at least one load (14) independent of connection to the
21. power grid (10).

1 2.   The fuel cell-powered generating system (8) of claim

2 1 wherein each fuel cell power plant (18) includes a

3 fuel cell and associated sub-systems (F. C.) for

4 generating power, a power plant controller (PPC) for

5 controlling and monitoring the condition of the fuel

6 cell and support sub-systems (P. C.), and a power

7 conditioning system (PCS) for conditioning the

8 power provided by the fuel cell to the loads, the power

9 plant controller (PPC) further including signal

10 processing logic (77, 79, 81, 85, 87) responsive to

11 signals indicative of the monitored condition of the

12 fuel cell and support sub-systems (F. C.) for providing

13 a signal (Kw Capacity - 88) representative of the

14 instant power output capacity of the respective fuel

15 cell power plant (18) , and wherein the site management

16 system (11, 94) is responsive to the instant power

17 output capacity signals (Kw capacity - 88) from each of

18 the fuel cell power plants (18_{1-n}) for providing a

19 signal (Total Kw Capacity - 95) representative of the

20 total instant power output capacity of the multiple

21 fuel cell power plants (18_{1-n}).

1 3.   The fuel cell-powered generating system (8) of claim
2 2, further including a utility dispatch signal (58,97)
3 received from the utility, and wherein the site
4 management system (11) includes signal processing
5 means (96, 97, 110) responsive to the utility dispatch
6 signal (58, 97) and the Total Kw Capacity signal (95)
7 for selecting the lesser thereof to provide an Actual
8 Dispatch signal (98) and for comparing the Actual
9 Dispatch signal (98) with the Total Kw Capacity signal
10 (95) to provide a pro-rated dispatch signal (100), and
11 responsive to the pro-rated dispatch signal (100) and
12 to the Kw Capacity signals (88) from each of the
13 respective fuel cell power plants (18) to provide
14 respective Set Power control signals (112, 90) for
15 controlling the dispatch power for each respective fuel
16 cell power plant (18_{1-n}).

1 4.   The fuel cell-powered generating system (8) of claim
2 3 wherein the signal processing means (96, 97, 110) of
3 the site management system (11) determines the
4 mathematical product of the pro-rated dispatch signal
5 (100) and each of the Kw Capacity signals (88) from
6 each of the respective fuel cell power plants (18), to
7 provide each of the respective Set Power Control
8 signals (112, 90).

1 5.   The fuel cell-powered generating system (8) of claim

2 1, further including a utility dispatch signal (58, 97)

3 received from the utility, each fuel cell power plant

4 (18) including a fuel cell and associated sub-systems

5 (F. C.) for generating power, a power plant controller

6 (PPC) for controlling and monitoring the condition of

7 the fuel cell and support sub-systems (P. C.), and a

8 power conditioning system (PCS) for conditioning the

9 power provided by the fuel cells to the loads, the

10 power plant controller (PPC) further including signal

11 processing logic (77, 79, 81, 85, 87) responsive to the

12 signals indicative of the monitored condition of the

13 fuel cell and support sub-systems (F. C.) for providing

14 a signal (Kw Capacity - 88) representative of the

15 instant power output capacity of the respective fuel

16 cell power plant (18), and wherein the site management

17 system (11) includes signal processing means for

18 dividing the utility dispatch signal (58, 97) by the

19 multiple number of fuel cell power plants (18) to

20 provide an initial per power plant dispatch signal

21 value, for comparing the Kw Capacity signal (88) for an

22 initial fuel cell power plant (18) with the per power

23 plant dispatch signal value and assigning to that plant

24 as much of the per power plant dispatch signal value as

25 allowed by the respective Kw Capacity signal (88), for

26 storing any remainder value in overflow storage, for

27 similarly comparing and assigning to each successive

28 one of the multiple fuel cell power plants (18) as much

29 of the per power plant dispatch signal value as allowed

30 by the respective Kw Capacity signal (88) and storing

31 any respective remainder value, and for iteratively

32 repeating the foregoing functions to allocate any

33 remainder value remaining in the overflow storage.

1 6.   The fuel cell-powered generating system (8) of claim
2 2, wherein the site management system (11) includes
3 a power monitor (68) for providing a signal (69)
4 representative of the total power demand of the
5 connected loads (14_{L1-LX}), and further signal processing
6 logic (34, 29) for comparing the total power demand
7 signal (69) and the Total Kw Capacity signal (95) and, if
8 and to the extent the total power demand exceeds the
9 Total Kw Capacity, shedding one or more loads (14_{L1-LX}) in
10 accordance with a predetermined schedule.

1 7.   The fuel cell-powered generating system (8) of claim
2 6, wherein each of the multiple loads (14_{L1-LX}) is
3 connected to the fuel cell power plants (18) through
4 respective selectively controlled contactors (13_{L1-LX}), and
5 wherein said shedding of one or more of the loads   is
6 effected by selectively opening respective ones of   the
7 contactors (13_{L1-LX}).

1 8.   The fuel cell-powered generating system (8) of claim
2 1, wherein the site management system (11) is connected
3 to receive dispatch signals from and provide status
4 signals to, the remote utility via communications
5 linkage (58, 62, 64, 61) connected between the site
6 management system (11) and the utility.

1 9.   The fuel cell-powered generating system (8) of claim
2 8, wherein the site management system includes a site
3 supervisory controller (29) for effecting the
4 integrated control of the multiple fuel cell power
5 plants (18) and providing the control interface with
6 the utility.

1 **10.** The fuel cell-powered generating system (8) of
2 claim 9, wherein the site management system (11) includes
3 a means (60) operatively connected with the site
4 supervisory controller (29) for manually selecting
5 operation of the generating system (8) either in a
6 local operating mode in which the multiple power plants
7 (18) are controlled individually or in a supervisory
8 operating mode in which the multiple power plants (18)
9 are operated in a unified manner.

1 **11.** The fuel cell-powered generating system (8) of
2 claim 1, wherein the site management system (11)
3 comprises a site supervisory controller (29) for
4 effecting the integrated control of the multiple fuel
5 cell power plants (18), a load shed controller (34)
6 connected (38, 70) to interact with the site
7 supervisory controller (29) and the loads (14, 13) to
8 control load shedding, and a site management controller
9 (31) connected to each of the fuel cell power plants
10 (18) for controlling the power provided by the power
11 plants (18) to the loads (14).

1 12.   The fuel cell-powered generating system (8) of
2 claim 2, wherein the site management system (11)
3 comprises a site supervisory controller (29) for
4 establishing, in response to a power dispatch signal
5 from the utility, the power dispatch loading of the
6 fuel cell power plants (18) in an integrated manner
7 when operating in the grid connected mode, a load shed
8 controller (34) connected (38, 70) to interact with the
9 site supervisory controller (29) and the loads (14, 13),
10 and a site management controller (31) connected to the
11 PCSs of each of the respective fuel cell power
12 plants (18) for controlling the transition of each fuel
13 cell power plant (18) from operation in one of the grid
14 connected and the grid independent modes, to operation
15 in the other.

1 13.   The fuel cell-powered generating system (8) of
2 claim 12, wherein said site management system (11)
3 further includes high speed, static switching means
4 (12) connected to the utility grid (10), the fuel cell
5 power plants (18, 15), and the loads (14, 13, 39) for
6 rapidly disconnecting the loads (14) and the fuel cell
7 power plants (18) from the utility grid (10) and
8 transitioning from the grid connected mode of operation
9 to the grid independent mode of operation.

1 **14.** The fuel cell-powered generating system (8) of

2 claim 2, wherein initial power rating signals (Kw

3 Rating-76) representative of a base power capacity are

4 provided for each of the multiple fuel cell power

5 plants (18_{1-n}), and the signal processing logic (77, 79)

6 is responsive to the monitored condition of each of the

7 respective fuel cells and support sub-systems (F. $C._{1-n}$)

8 to foldback the base power capacity (Kw Rating-76) of

9 the respective power plant (18) by an amount

10 predetermined in accordance with the monitored

11 condition to thereby provide the respective instant
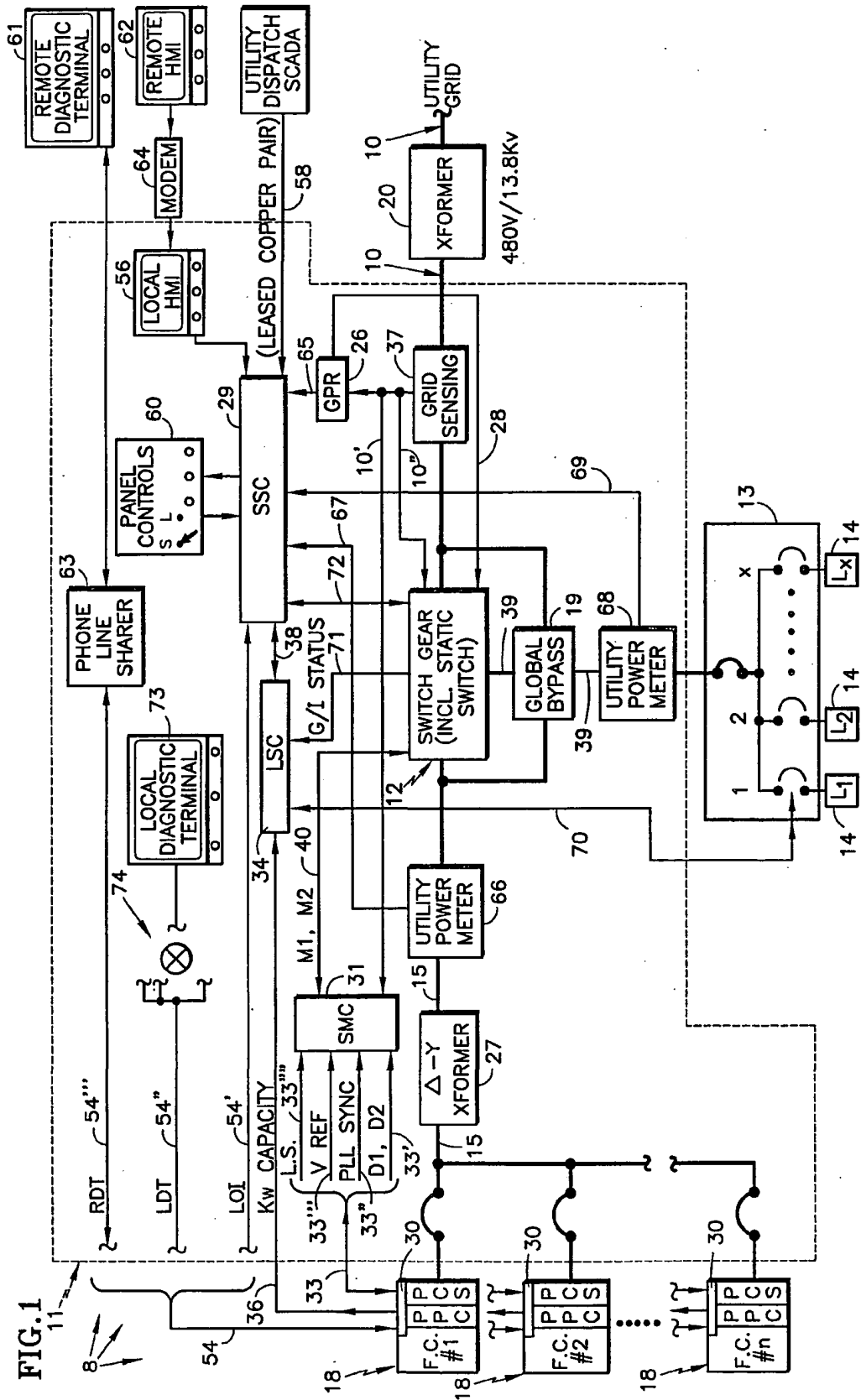
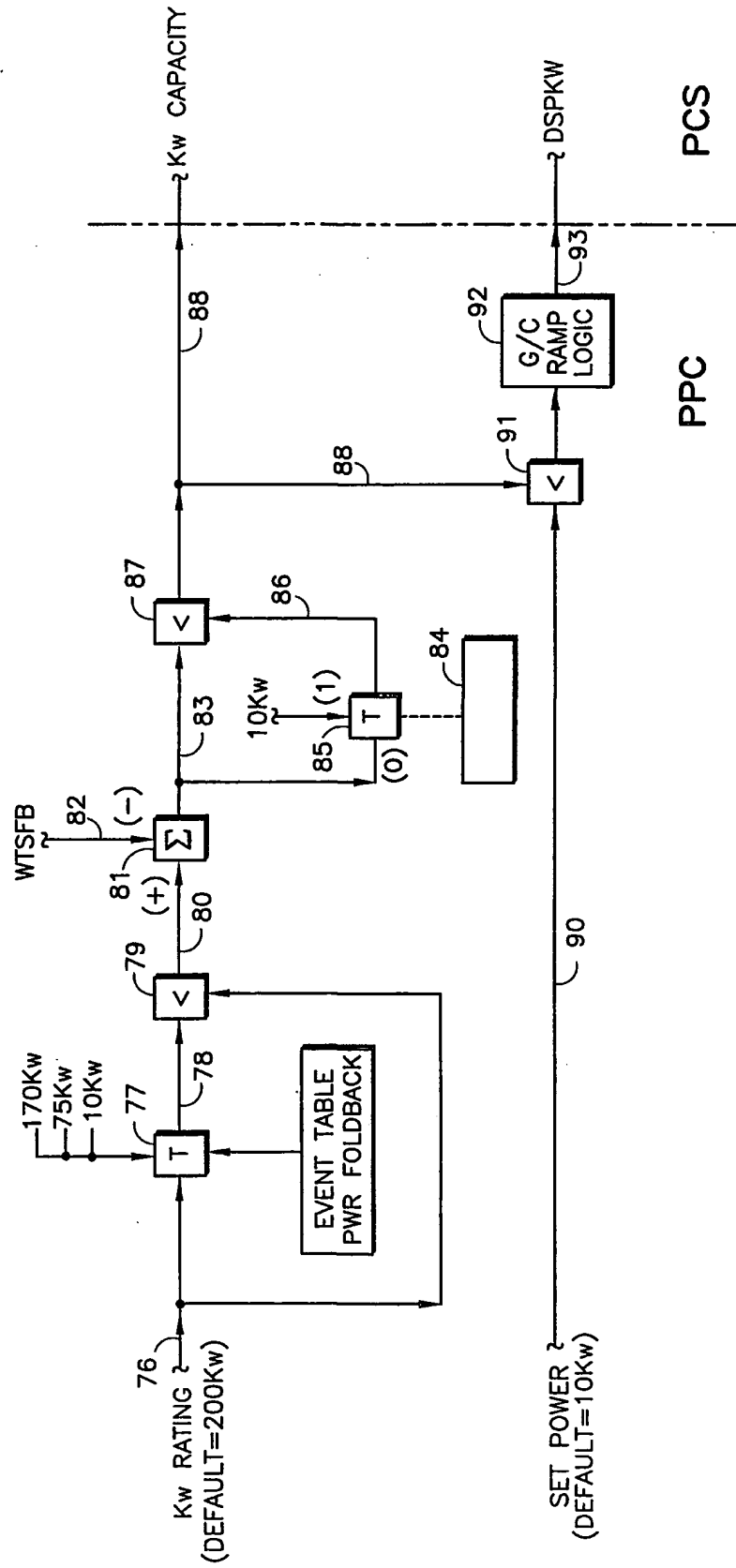12 power output capacity signal value (Kw Capacity-88).

FIG.1

FIG.2

FIG.3